High-Resolution, Nonhydrostatic Simulations of Internal Wave Generation in the Luzon Strait using SUNTANS

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Grant Number: N000140910261

LONG-TERM GOALS

The long-term goal of these numerical simulations will be to obtain a detailed understanding of the fundamental physics that govern internal wave generation over complex topography, with a specific focus on flows through the network of straits and sills between the islands of Taiwan and Luzon.

OBJECTIVES

The following objectives are planned to support this study:

- Influence of bathymetry and grid resolution: Assess what bathymetric and accompanying grid resolution are needed in order to obtain meaningful results
- Internal wave energetics: quantify how internal wave energy partitioned
- Three-dimensional process studies: determine the importance of rotation and the ratio of strait width to strait depth
- Assessment of nonhydrostatic effects: understand the role of nonhydrostatic pressure in the vicinity of steep and complex bathymetry

APPROACH

The work for the IWISE DRI will be divided into several thrust areas that are divided between Drs. Jachec and Fringer (co-PI). Dr. Jachec is responsible for: 1) assessing effects of grid resolution and bathymetry, 2) computing energetics, 3) performing three-dimensional simulations of candidate field sites; 4) performing three-dimensional process studies. Drs. Jachec and Fringer are cooperating in assessing the role nonhydrostatic effects on internal wave generation.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**
4. TITLE AND SUBTITLE **High-Resolution, Nonhydrostatic Simulations of Internal Wave Generation in the Luzon Strait using SUNTANS (FIT)**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Florida Institute of Technology,Dept. of Ocean Engineering,150 W. University Blvd,Melbourne,FL,32901**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Analysis of bathymetry and grid resolution

As pointed out by Jachec et al. (2007) when applying SUNTANS to simulate internal tides in Monterey Bay, the success of a high-resolution simulation of internal waves depends to great extent on the accuracy of the available bathymetry and the accompanying grid resolution (Figure 1).

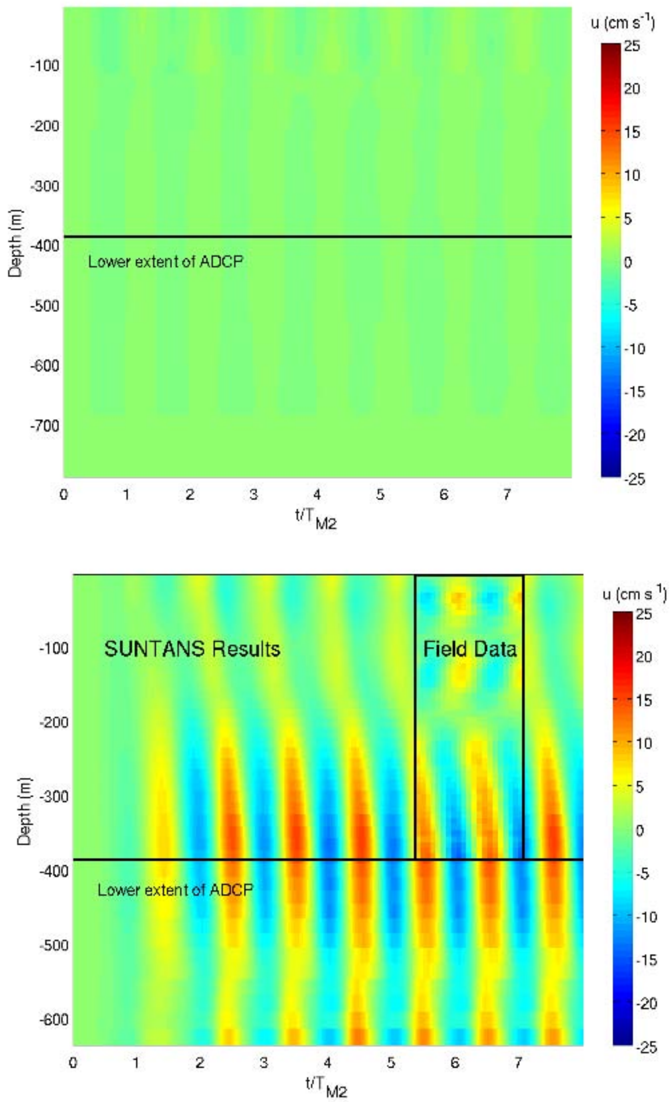

Figure 1: Time-series model results of velocity (number of M_2 tidal cycles) within Monterey Submarine Canyon using coarse (upper panel) and fine grid resolution (lower panel). Field data are overlaid in the lower panel for comparison (Jachec et al., 2007).

We expect bathymetry to be even more crucial to obtaining accurate predictions of both barotropic and baroclinic velocity fields in the Luzon Strait because the magnitudes of the currents are one order of magnitude stronger in the Luzon Strait than they are in Monterey Bay, and the bathymetry is much more complex. In order to assess the accuracy of the bathymetry, we will work with other participants in the DRI (we have discussed this issue at length with Harper Simmons (UAF) and Ren-Chieh Lien (UW) who also agree that bathymetry is crucial for accurate simulations of generation in the Luzon

Strait) to develop a catalogue of available bathymetry and perform simulations with this bathymetry to assess its reliability in computing accurate barotropic currents. Should high-resolution bathymetry become available, we will perform grid-resolution studies to determine grid-independence in computing the barotropic currents. Following the work of Simmons et al. (2004), we will also plan on assessing the effects of filtering the bathymetry given a high-resolution grid to determine how the filtering and interpolation schemes influence the behavior of the simulations to obtain an idea of both minimum bathymetric and grid resolution requirements to achieve accurate simulation results.

Analysis of internal wave energetics

Numerous authors have computed the baroclinic energy flux in the Luzon Strait to determine the likely source of internal waves (see Section 1), and the results indicate that the eastern Lan-Yu ridge is responsible for most of the generation. Following the work of Jachec et al. (2006), who calculated the internal wave energy flux in Monterey Bay, we will perform high-resolution calculations of the internal wave energy flux in the Luzon Strait to obtain detailed maps of baroclinic internal wave energy flux divergence throughout the region. These calculations will help determine the distribution of internal wave generation along the Lan-Yu ridge. Because of the strong currents in the region, it is likely that the nonlinear and nonhydrostatic terms in the energy flux budget (Venayagamoorthy and Fringer, 2002; Moum et al., 2007) will be significant. We will calculate these terms along with a direct assessment of the conversion of barotropic to baroclinic energy using the method outlined by Carter et al. (2008), who calculated the conversion with very high resolution at the Hawaiian Islands. An assessment will be made of the contribution of each of the dominant tidal components (M2 and K1) individually and mixed (see, e.g. Zhang and Fringer, 2006b).

Three-dimensional process studies

Our field-scale simulations will be augmented with process studies of nonhydrostatic generation in straits and over idealized sills to help understand the specific physics of generation at the field sites. Numerous questions will remain unanswered because several processes inherent to internal wave generation in the Luzon Strait are three-dimensional. The most obvious of these is the influence of rotation. Helfrich (2007) developed a set of weakly nonlinear equations to analyze the influence of rotation on the propagation of nonlinear internal waves, and showed that true solitary wave solutions do not exist in the presence of rotation because short wave energy is fed back into long wave motions periodically over the inertial time scale. While the waves are solitary wave-like in that they appear as trains of internal waves at the leading edge of the internal tides, the packets appear and disappear every inertial period as rotational dispersion causes the inverse energy cascade to the long-wave motions. While this behavior may not be evident until at least one inertial period after generation, it does indicate that other rotation processes may be important during generation. In particular, rotation may have a significant impact on the generation of the depression waves that form on the ebb tide (as explained by Ramp et al., 2004) since the length scale of these depression waves is on the same order as the internal Rossby radius of deformation. The effects of rotation may lead to a smaller depression wave because of the right-turning tendency of flows in the northern hemisphere. To test this hypothesis, we will study the generation of internal waves through a simple strait, as shown in Figure 2. In addition to the introduction of rotation, this bathymetry introduces the width of the channel as an additional length scale that influences the dynamics. We will study the influence of the channel width to depth ratio both with and without rotation. It is expected that nonhydrostatic effects will be significant at the strait where the grid resolution will be extremely fine (Xing and Davies, 2006).

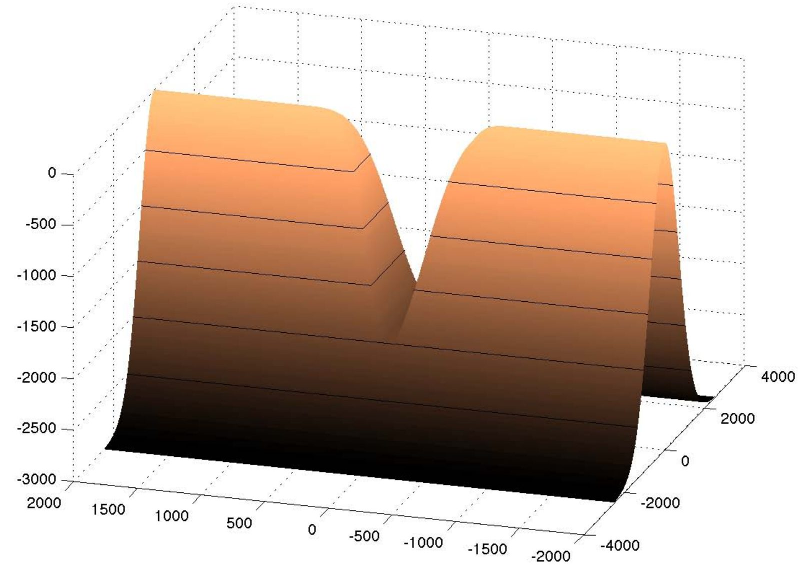

Figure 2: Three-dimensional strait geometry created by a two-dimensional sill incised by a channel. Barotropic tides would be imposed to generate flow through the channel in the longitudinal direction.

Nonhydrostatic Effects

A bulk of the internal wave activity in ocean basins such as the SCS can be represented with a hydrostatic model. This is clearly demonstrated by our internal wave simulations with SUNTANS in its hydrostatic mode (Zhang and Fringer, 2006a,b; Jachec et al., 2006) and those of other investigators, such as Petruncio et al. (2002), Simmons et al. (2004), Niwa and Hibiya (2004), and Holloway and Merrifield (1999). Using simulations over idealized topography with SUNTANS, Zhang and Fringer (2007) showed that hydrostatic and nonhydrostatic internal wave propagation differs mostly in the amplitude and number of waves in the weakly nonlinear wave trains that evolve, while the position of the leading edge of the trains depends weakly on nonhydrostatic effects. This has important ramifications for the predictability of internal wave amplitude but shows that internal wave phase can be predicted reasonably well with hydrostatic models.

WORK COMPLETED

Funding began mid FY2009, and an HPC account for Dr. Jachec was secured summer 2009 at MHPCC (JAWS has been decommissioned recently; Dr. Jachec is gaining access to MANA).

Initial three-dimensional processes based grids have been developed to assess the relative role of strait width (w) to strait depth (d). The role of Coriolis force is being assessed.

RESULTS

Various initial numerical simulation setups are underway. However, no results are ready to be presented at this time.

IMPACT/APPLICATIONS

The numerical simulation results will yield fundamental physics that are important to internal wave generation in straits and over sills. Furthermore, field-scale modeling will be used to help guide upcoming field efforts (e.g., positioning of assets) in the Luzon Strait.

RELATED PROJECTS

At the invitation of Dr. Glen Gawarkiewicz from WHOI, Dr. Jachec (WHOI Guest Investigator) is performing two-dimensional field-scale simulations of internal boluses in the South China Sea. Together, they are looking into the role of mixed tides to generate these observed phenomena. A preliminary plot of the internal tide at the ASIAEX site is presented in Figure 3. The color contours are baroclinic velocity (m/s) and the black lines are isopycnal displacements. Note the growing nonlinearity at X=70,000 m as demonstrated by the steepening face. Dr. Gawarkiewicz and Dr. Jachec have submitted an abstract to Ocean Sciences 2010 on this work. Dr. Jachec intends to pursue studying the evolution of internal waves as part of his ONR YIP 2010 application with a specific interest in dissipation mechanisms, such as breaking.

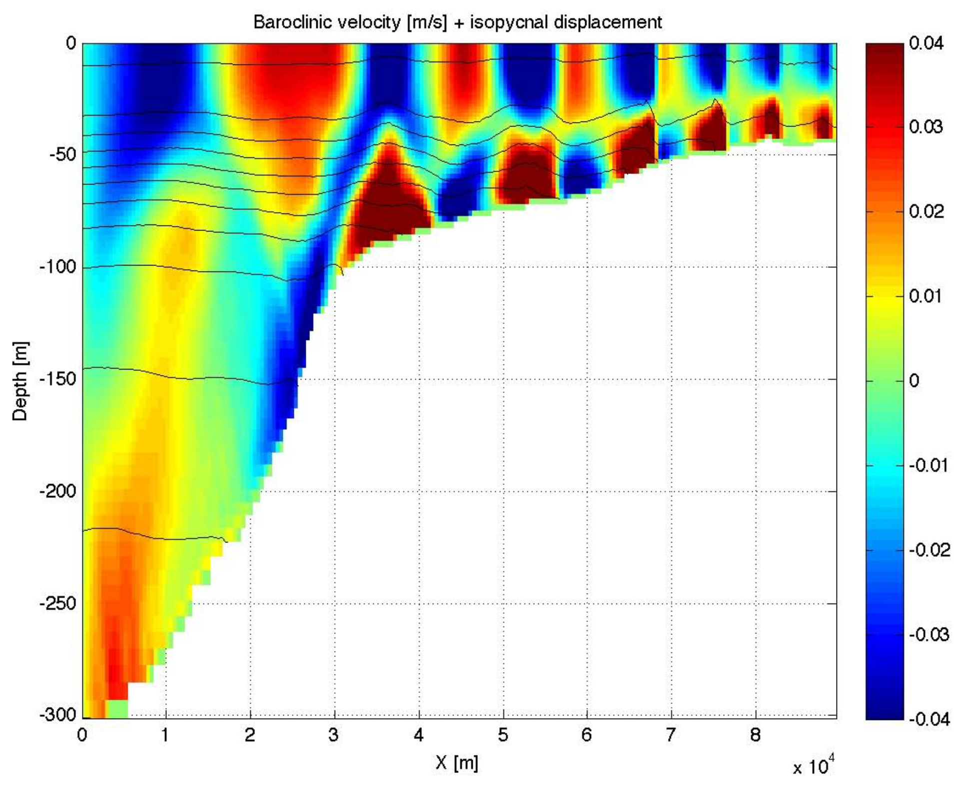

Figure 3: Numerically simulated baroclinic velocities and isopycnal displacements at the ASIAEX site.

NRLSSC invited Dr. Jachec to apply SUNTANS to identify hydraulically controlled flows in the absence of ambient currents and assess the effects of nonhydrostatic pressure on the resulting hydrodynamics in the Turkish Straits system. This work initiates cooperation between Dr. Cheryl Ann Blain of NRL and the Dr. Jachec.

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HONORS/AWARDS/PRIZES

Steven M. Jachec, Physical Oceanography Dissertation Symposium (PODS) invited attendee (sponsored by ONR, NSF, NASA, and NOAA), 2008.